REVIEW ARTICLE

Human Exploration of Space: why, where, what for?

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Abstract

"Man must rise above Earth to the top of the atmosphere and beyond, for only then will he fully understand the world in which he lives" – Socrates (469-399 BC). The basic driving rationales for human space flight (HSF) are rooted in age-old and persisting dreams. Fascination with the idea of people going into the sky for adventures in other worlds goes back to ancient myths. This paper sheds light onto criticisms of HSF programs, by revisiting their scientific grounds and associated benefits, along with the different types of emerging commercial enterprise. Research from space has lead to a wealth of commercial and societal applications on Earth, building up the case for the so-called "Space Applications Market". Hippokratia 2008; 12 (Suppl 1): 6-9

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On the 50th anniversary of the launch of Sputnik on October 4th, 1957, the Soviet Union rocketed into leadership in this new technological frontier. It is said that the west was caught by surprise with Pravda's headline, "World's First Artificial Satellite of Earth Created in Soviet Union." The leader of the Sputnik project was Sergei Korolev who remained anonymous until his death nine years later. It should not come as a surprise to anyone who had watched German progress during World War II in the field of ballistic missiles with the V-2 bombers. These same German scientists and engineers joined the space programs in the USA and the Soviet Union after the war. A month later Sputnik II was launched. Warm air was piped into the capsule to keep the dog Laika comfortable amid the surrounding freezing temperatures, but rising temperatures due to thermal control problems killed Laika on the fourth day of the mission.

On April 12, 1961, cosmonaut Yuri Gagarin became the first human to be launched into space from Baikonur. He completed a single orbit of the Earth thereby firmly establishing the Soviet Union's leadership in space. The Space Race had started. The USA followed very soon with the Mercury, Gemini and the Apollo programs. But the race that Korolev had wanted to win most passionately was won by the USA, when on July 20th, 1969, Neil Armstrong and Buzz Aldrin landed on the surface of the Moon.

This, and the crash on the Moon of an unmanned Soviet spacecraft, led the Russians to withdraw from the race to the Moon. However, the start of a long and fruitful collaborative relationship developed instead between the scientists of these two competing powers. It continues to this day on the International Space Station (ISS).

Fifty years later, there are 43 countries who own satellites of various types in space while France, Russia, China, Japan and India are displacing the US from the commercial satellite launch market. Many countries have sent humans in space either on the US Shuttle or the Russian Soyuz. China launched its first human, Yang Liwei, in 2003. China is planning human lunar missions in the next decade. Today's leaders are those with heavy launch capabilities as the next prize is once more the Moon. Mars is a longer term exploration target. France, China and Russia currently possess such heavy launch capability. The US is working on replacing the aging Shuttle with solid-booster rocket Aries 1 and crew module Orion to get back into the lunar race by 2020, this time with longer stays in mind. In the meantime, Japanese, Selene, and Chinese, Chang-1, spacecraft are circling the Moon to acquire detailed mapping of its surface. European and US lunar satellites are also planned as well as landing robotic missions. Fifty years after Sputnik, The Space Race is of a very different nature.

Another commercial facet of the race is private commercial space travel. There have been about 29 non-career astronauts and cosmonauts who flew on the Shuttle and on Mir, and more recently paying space tourists – Tito, Olsen, Shuttleworth, Ansari, Symonyi – spent 7-10 days each on the ISS after selection and training by the Russian space program. Otherwise, experience of microgravity is currently limited to parabolic flights, but will soon include sub-orbital travel when the appropriate transportation systems are developed and tested. Tickets are already on sale.

The basic driving rationales for human space flight (HSF) are rooted in age-old and persisting dreams. Fascination with the idea of people going into the sky for adventures in other worlds goes back to ancient myths. It has been a major theme in science fiction from Jules Verne's From the Earth to the Moon to the present day. Its

wide and enduring appeal has been evident in the popularity of comic strips like Buck Rogers and Asterix, movies like 2001 and TV programs like Star Trek.

The development of rocketry that could place artificial satellites in orbit brought with it for the first time the possibility of attempting the realization of these dreams.

Criticisms of Human Space Flight

Over the years criticisms of HSF focused on expense because it is perceived as the costliest space activity diverting critical funds from social needs. The perception also is that it produces the fewest tangible benefits. Perhaps, the strongest criticisms of the benefits of HSF are the low value critics place on the scientific and other activities humans conduct in space.

One argument is that humans are not needed in space because the same or better work could be done with unmanned, robotic spacecraft. A more fundamental criticism is that laboratory experiments in space add little of scientific significance to what can be learned on the ground.

Those who defend HSF disagree. They point to the shuttle astronauts' repair of the crippled unmanned Hubble Space Telescope and the later upgrading of its instruments which made possible its great successes. They point to the long series of Shuttle flights on Spacelab built by the European Space Agency that made possible the transformation of the Shuttle from merely a transport system to a valuable laboratory. They stress particularly the possibilities they see in medical and physiological research conducted by humans, in both humans and other organisms that is expected to generate new science now not foreseen. Such research depends greatly on the availability of a well-equipped laboratory in space such as Skylab was in the early 1970s and whose research data still serves as the golden standard to this day. Soon the International Space Station (ISS) when complete with the addition of ESA's Columbus module and the Japanese Experimental Module (JEM) should provide the opportunity to fulfill this promise.

There are more arguments for HSF. No exploration dream beyond earth, whether it be lunar bases or a voyage to Mars or beyond, will be possible without first gathering crucial knowledge and testing new technologies in microgravity. Fast-growing commercial space travel ventures will depend on expertise gained from the experience of HSF to assure the safety and provide support to private space adventure travelers.

Furthermore, intelligent, skilled humans available onboard will be able to tend or trouble-shoot technologies and experiments in physical, chemical, biological and biomedical sciences and test new exploration hardware. What is adequate and reliable in situations that can readily be accessed from earth for repair is wholly unacceptable on missions that could last up to three years with communication delays of 20 minutes or more. Nor will, for example, tweaking existing technology concepts for life support systems transform them into reliable, closed planetary standard hardware.

Completely new thinking and technical approaches that have as yet to be conceived, not to mention designed or tested, are required. For example, the proposed lunar space suit is an adaptation of the existing Extravehicular Activity (EVA) and Apollo suits and is probably no more comfortable to work in than those were. It may work fine for short stays on the Moon but certainly not for the proposed long habitation and surface exploration where pre-breathe and existing gloves, despite all costly efforts, continue to be painful to work in. The energy expenditure of astronauts in these suits is huge while tears or lunar or Martian dust may cripple a mission[1]. New revolutionary concepts such as that proposed by Professor Newman at MIT using pressure instead of vacuum in a skin-tight suit that can be easily repaired with a patch is an excellent example of the kind of thinking required[2]. And it is not an either/or issue. As is happening with the re-visitation of the Moon today, robotic missions are inexorably tied with HSF. They must proceed to systematically map and gain as much knowledge as possible of the Moon by setting the scene and subsequently supporting humans after they land and settle.

Science and Benefits

Expectations initially conceived of HSF as providing the human-tended, microgravity environment to develop new technologies and products that complete industrial manufacturing plants would soon appear orbiting around Earth have not materialized. Though this may happen one day it does not appear likely to happen soon. The main reason, of course, is the reality of problems accessing space platforms like the ISS. The low number of flight opportunities, the high costs and the long intervals associated with performing experiments in space leads reduces the chances of any commercial product going to market within acceptable time limits. Questions about the quality of the research came from the inability to design, repeat or confirm experiments in ideally controlled conditions to draw sound conclusions. As in any new field, those scientists who persisted produced the observations and data that intrigued and enticed others. But research suffered as early projections of up to 60 Shuttle launches per year remained a fantasy and with them ambitions for the industrialization of space.

A different type of commercial enterprise emerged than was originally envisioned. Research from space is leading to a wealth of commercial and societal applications on Earth.

The Case for the Space Applications Market

The applications of technologies developed for use in space have been around for many years and are well known. One of my earliest experiences came from our life support research program in 1967 and involved applying a very thin polymer film on the visor of the space suit to protect it from scratching and from the sun's glare. This technology was picked up 10 years later by Foster

Grant, a company that manufactures all types of eyeglasses. Now every pair of glasses in the world is dipped in such a protective coating. Another need was the requirement to miniaturize, automate and remotely operate technologies in space. Doctors monitoring the health of astronauts on Skylab in 1973-1979 requested several blood samples throughout the mission which spanned 28-84 days, each requiring at least 60ml of blood drawn. The information they required was impossible to obtain and the samples were too bulky to store and bring back until a huge effort was started to develop analytical procedures for hormones, electrolytes and other blood constituents to reduce by at least ten times the amount of blood needed to be drawn. No such requirement existed in hospitals and medical practice. Today, hospitals and clinics can run comprehensive medical profiles on a few drops of blood.

The need to monitor the health of astronauts at a distance gave birth to the field of telemedicine. Today, medical care in rural and other remote communities is supported with access to experts in a distant country. This also includes intricate surgery. Technologies to monitor astronaut health during space missions helped create implantable medical devices used to monitor in utero through telemetry, the heart of fetuses that might be in distress. Converging advances in miniaturization, automation, and remotely operated technologies have for some time been revolutionizing medicine, bioinformatics, biosensors, nanotechnology and more. The demanding technology of space compelled us to push the limits of human science and engineering achievements which, in turn, is pushing technology on Earth further. Without the innovation that spaceflight demands, we would not have this technology for improved environmental monitoring, defense or the health of individuals. For example, sensors encoded with genetic information of any genetically sequenced pathogen can now detect its presence even in minute concentrations. These can be used in air and water purification systems.

There are clear economic and social benefits as well. Micro-electromechanical Systems (MEMS) used to monitor astronaut health and activities is a technology whose current applications include accelerometers, pressure, chemical and flow sensors, micro-optics, optical scanners and fluid pumps. The MEMS industry has a projected 10-20% annual growth rate.

Mammography used Hubble digital imaging system for greater diagnostic precision. Working with the National Cancer Institute and General Electric, we applied this enhanced precision and the technique for breast biopsy to outpatients and increased the accuracy of breast cancer diagnostic procedures.

Tissue engineering for repairing damaged organs has endless applications. It came from biological research designed to understand the effects of gravity and microgravity on human tissue. In Earth's gravity a cell culture grows in two dimensions, flat on a plate. In space, without gravity, it grows three-dimensionally more like human tissue looks. Three-dimensional tissue was generated on the ground in a bioreactor at NASA's Johnson Spaceflight Center in 1987. A slowly rotating vessel neutralizes the pull of gravity on the cells allowing them to remain suspended as they do in space. The bioreactor has become the 'industry standard' for culturing a number of medically important types of cells on Earth like collagen, skin cells and kidney cells that might in the near future be used in organ repair.

Cells multiply faster in space. The virulence of salmonella increases in microgravity as do viruses like herpes. The sensitivity of salmonella to antibiotics decreases. The immune system is depressed in astronauts. A 200% increase in the formation by microbial fermentation of the antibiotics Monorden and Actinomycin D was found even after a few days on a Shuttle flight. The pharmaceutical industry uses this production process in the formation of antibiotics. Even a small increase in the operational efficiency of Earth-based processes could provide substantial economic and health application gains. The composite knowledge from these space observations is invaluable in determining ways gravity, activity and the environment play in health and the spread and control of infectious disease.

Protein crystallography is yet another success story[3,4]. In 1995, Dr. Herbert A Hauptman, winner of the1985 Nobel Prize in Chemistry, commented in a letter to the US Congress: "I was initially skeptical about the possible benefits that might come from these efforts but I have clearly seen the advantages that this unique environment –space – has to offer in the area of protein crystallography"[3]. Protein crystallography is a tool used to determine the three-dimensional structures of proteins. Once a pharmaceutical company has this information, it is able to tailor drugs to target specific proteins, as for example in interfering with the function of such proteins in Alzheimer's Disease or infectious agents like tuberculosis[5]. Obtaining crystals of sufficient size and purity on Earth is a slow and tedious process with a success rate of 6 to 33% depending on the prior purification steps. This implies that the majority of crystals obtained in this way are not of sufficient quality to result in a structural solution. In the microgravity of space, crystals grow more slowly and yield larger crystals of significantly greater purity.

Astronauts and cosmonauts return from space showing a set of symptoms that taken together are those associated with aging. This has been known since the beginning of the space program and especially emphasized by the biomedical data from Skylab and the Russian Salyut longer missions[6].

It, therefore, became necessary to find a way to induce these symptoms in healthy volunteers on the ground to identify the mechanisms by which those changes were produced so that appropriate countermeasures could be found. The model of choice to enable the study on the ground of changes produced in astronauts in space has been bed-rest – lying in bed continuously for days at a time, especially with the head lower than the feet at -6° (HDBR). Since it is impossible to escape the force

of gravity on earth for any length of time, what this position essentially does is minimize its effectiveness by pulling across the chest (Gx) instead of from head-to-toe as in the upright position (Gz)[7]. From the beginning of the space era even up to and including the publication of Inactivity: Physiological Effect*s* in 1986[8], the general assumption was that these changes were exclusively due to the inactivity and immobilization inherent in lying in bed or secondary to living without gravity. Therefore, the search for countermeasures to maintain astronaut health centered on exercise. However, in the last 20 years[7] it became apparent that even intensive exercise was only partially helpful as a countermeasure. Efforts took a more basic approach to identify the nature and variety in which the gravity stimulus acts on the human body and the way in which humans physiologically sense and respond to gravity stimuli. One of the outcomes from space with broadest applications for the health and quality of life of humans on earth has come from this research.

Like space, lying continuously in bed telescopes in healthy young individuals what happens to all on earth over many, many years. For instance the normal average rate of loss of bone density on earth is about 1% per year, whereas in space it is 0.4-1% a week and in bed-rest it is about 1-1.5% a month. This approach allows over a relatively short period of time the study of the development and progression of these changes. They are considered reversible in healthy adults recovering from 6 months in space or lying in bed for up to 3 months. However, they have generally been presumed to be irreversible with age. A sedentary lifestyle is now known to lead in the long run to common medical conditions like, for example. a prediabetic state leading to Type-II diabetes, heart disease, stroke, deep vein thrombosis and balance and coordination disorders[9].

As the value of research from bed-rest studies gains acceptance, many more such studies are being conducted around the world. They are being used as a tool in understanding human physiology in the elderly as well as in clinical and nursing conditions. Health insurance companies have seen economic gain in encouraging patients to reduce hospital stays from the application of results of such studies that show recovery is accelerated after surgery if patients are treated as outpatients or are encouraged to get out of bed and move about as soon as possible. The development of countermeasures for the purpose of preserving the health of space travelers are directly relevant to protecting the health and strength of all of us living on earth. More immediately, such data are directly applicable to prevent the inactivity-related diseases of today and accelerate recovery and rehabilitation of the sick, the elderly, the injured and the disabled here on earth.

These are just a few examples of the benefits to date from space research – a whole new and exciting world of exploration lies ahead.

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